Funny Things Meanders Do: A Summary of the Diversity of Meander Processes and Morphology and Implications for Reservoir Geometry and Quality within Channel Belts*

John M. Holbrook[1]

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Abstract

The generation of point bars by lateral accretion during lateral expansion and downstream translation of river meanders are well-described processes, and a primary means for generation of sandy bar reservoirs within fluvial strata. More recently, the concept of "counter" point bars has been stressed to explain meanders with concave growth ridges that tend to form mud-rich bar systems with low reservoir quality. Detailed mapping within the Missouri River system reveals a wide diversity of meander style. These styles include translation, expansion, and counter point bars, and three additional variations: wavering meanders, spinout meanders, and meander pile ups. Wavering meanders superficially resemble point-bar meanders but did not grow by lateral accretion. Instead, these form by repeated accretion of mid-channel bars to the channel bank in otherwise braided reaches. The result is an amalgamated set of small fusiform bars that collectively form a larger arced meander form. Since the mid-channel bars can accrete to either the outer or the inner bank, the meander can grow in both outward and inward directions, and may thus "waver." The resulting reservoir is an amalgamated set of smaller channel bars separated by shallow channel fills with excellent reservoir connectivity and quality within and between these meander lobe deposits. Also within the braided section occur highly contorted "spin-out" meanders. These occur locally and randomly in both time and space and record short sections of braided river that are temporarily compressed into single-thread channels. The energy within the system exceeds the stability of sustained meandering. The loop is characterized by rapid point-bar accretion that generates complexly compound forms. After this brief "spin out", the meander is quickly cut off, and the river returns to its normal braided pattern. These meanders form large high-quality sandbar reservoirs with unusual shapes, and well-defined bounding channel fills. Meander pile-ups occur where tips of normal expanding and/or translating meanders encounter bedrock constrictions. Here, bedload transport is locally concentrated. Sedimentation forces accelerated bar growth in the area around the constriction. Likewise, downstream bar translation is stopped. Meanders "pile up" on the floodplain preserving multiple and abundant crosscutting meanders with hairpin form. Reservoirs are sandy but narrow and long and dissected by channel fills.

Selected References

Holbrook, J., R.W. Scott, and F.E. Oboh-Ikuenobe, 2006, Base-level buffers and buttresses: a model for upstream versus downstream control on fluvial geometry and architecture within sequences: JSR, v. 76, p. 162-174.

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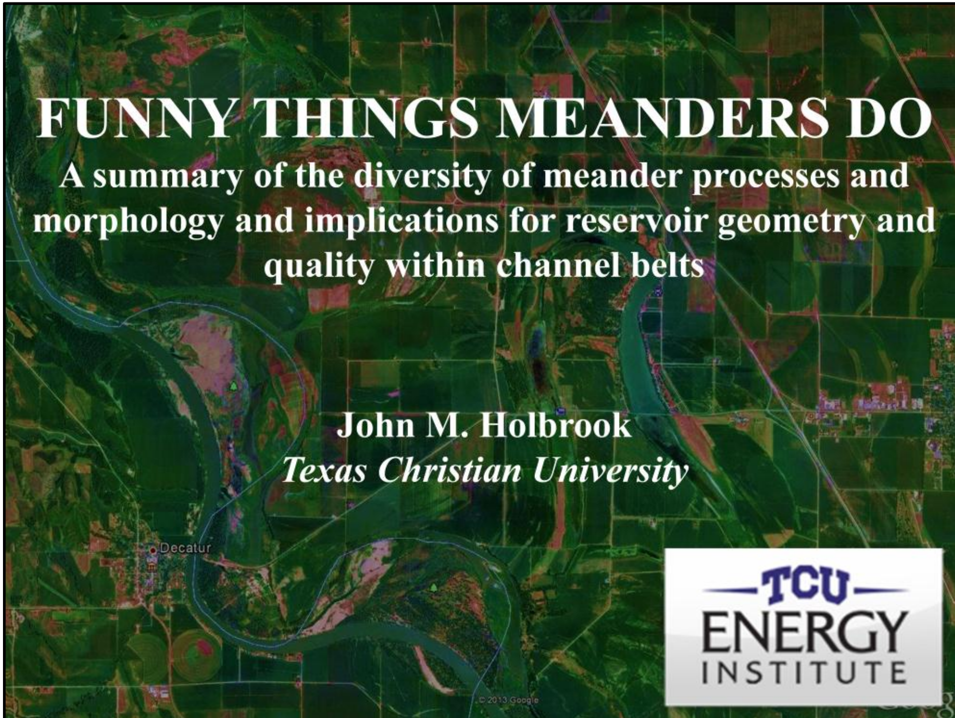
FUNNY THINGS MEANDERS DO

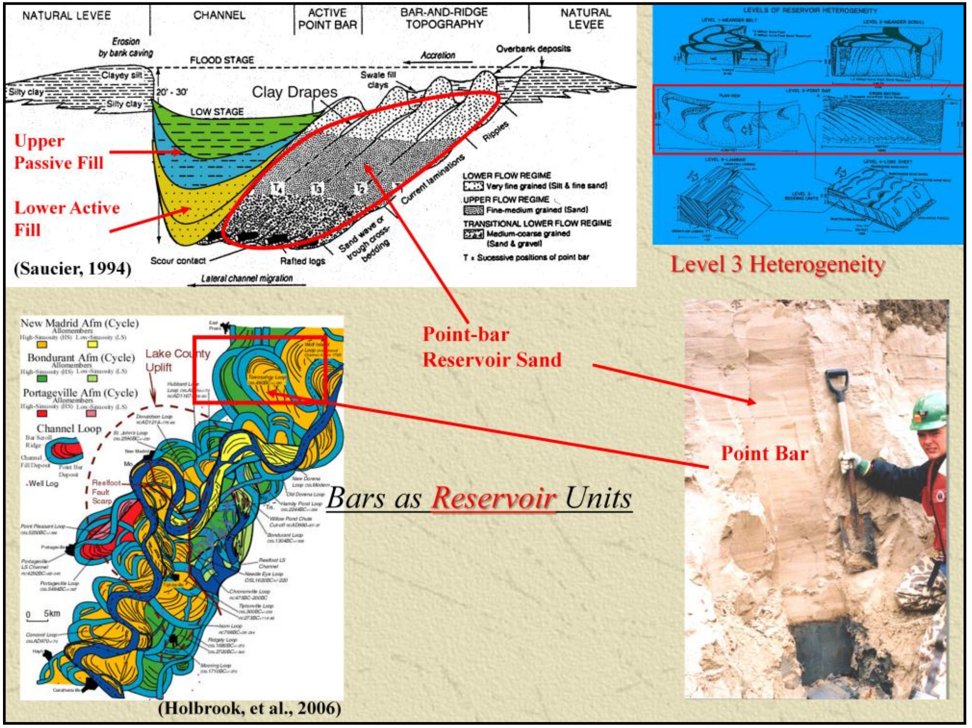
A summary of the diversity of meander processes and morphology and implications for reservoir geometry and quality within channel belts

John M. Holbrook

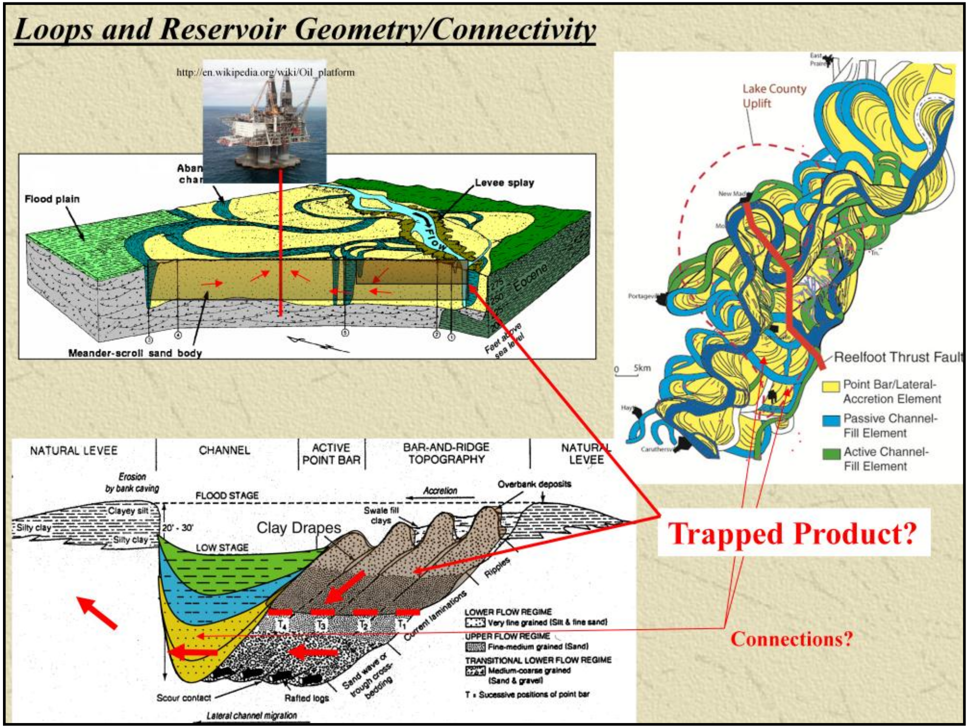
Texas Christian University



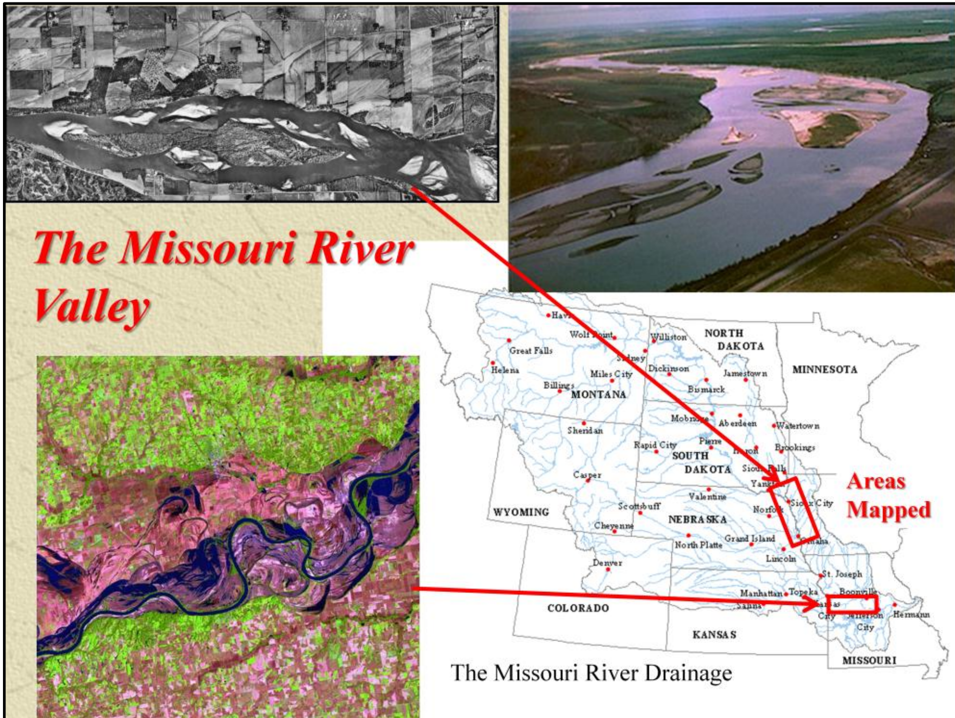
TCU ENERGY INSTITUTE



Presenter's notes: Bar deposits like these point bars are the main reservoir target. Point-bar units form the sandy reservoir lithofacies. These are wrapped by finer channel-fill allounits, and are typically constructed of medium-to-fine-grained medium-sorted cross-bedded-to-planar-laminated sand with local thin-to-medium-bed-thickness mud drapes. Point bars fine upward from coarse to fine sand and are capped by levee/splay and mud veneer strata. Point bars record lateral migration of the channel and accretion deposition of sandy bar strata in the channel's wake.

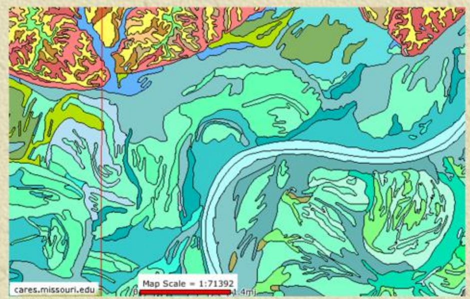


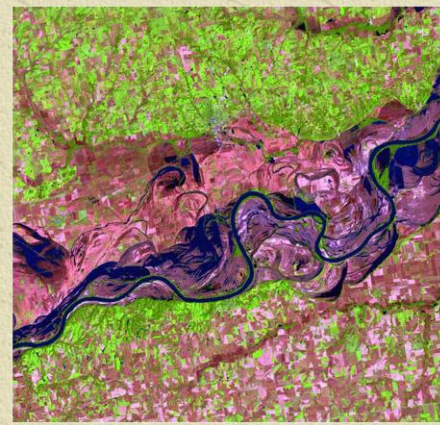
Presenter's notes: Even though flow can likely get under the channel to connect the bars, the upper channel is a barrier and prone to trap fluids. In addition, special consideration should be given to heterogeneity when draining a channel-belt reservoir. Drill penetration of a belt will only generally penetrate a single point bar, which will be compartmentalized by an engulfing channel fill. Production will drain the petroleum within the penetrated point bar readily, but production of petroleum from adjacent point bars requires connections. Passive channel fills will be highly effective barriers to flow and active fills will be moderately effective barriers. This means that connection between point bars will need to be made through the base of channel fills. Even if basal connection is effective, some substantial proportion of the petroleum can be trapped against channel fills in the tops of non-penetrated point bars. A production plan needs to compensate according to recover these fluids.


The Missouri River Valley
Areas Mapped
The Missouri River Drainage
NORTH DAKOTA
MINNESOTA
MONTANA
SOUTH DAKOTA
WYOMING
NEBRASKA
COLORADO
KANSAS
MISSOURI
Great Falls
Helena
Billings
Miles City
Williston
Dickinson
Jamestown
Bismarck
Aberdeen
Watertown
Brookings
Sheridan
Rapid City
Pierre
Casper
Valentine
Scottsbluff
Cheyenne
Norfolk
Sioux City
North Platte
Grand Island
Lincoln
Denver
St. Joseph
Manhattan
Topeka
Boonville
City
Hermann
Salina

Methods

- Constructing hypothesis maps
  - Using Remote Sensing Data
    - Satellite Images
    - Digital Elevation Models (DEM)
  - Existing maps
    - Topographic
    - Soil Maps



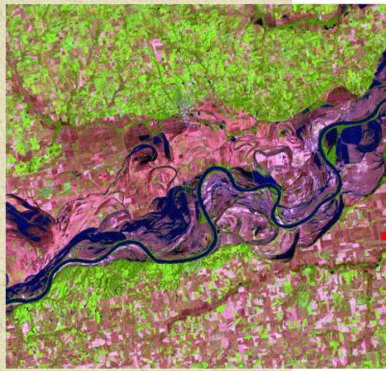


Hypothesis Testing

(Resources)

- Remote Sensing Data (satellite, air photos)
- Existing Maps (Saucier, 1994, Soil Survey, topos, etc.)
- **Field Sampling (Augers, Soil Probe)**

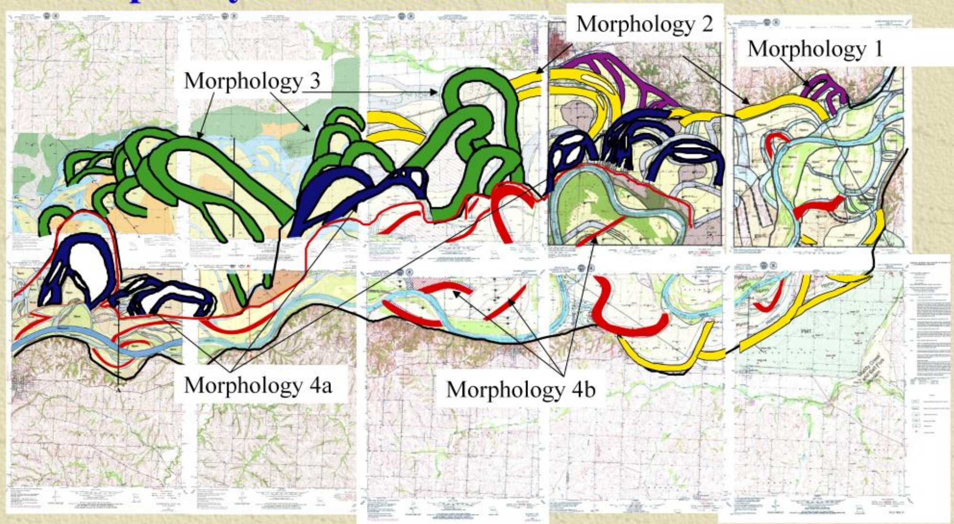
The Missouri River Valley



The Missouri River Drainage

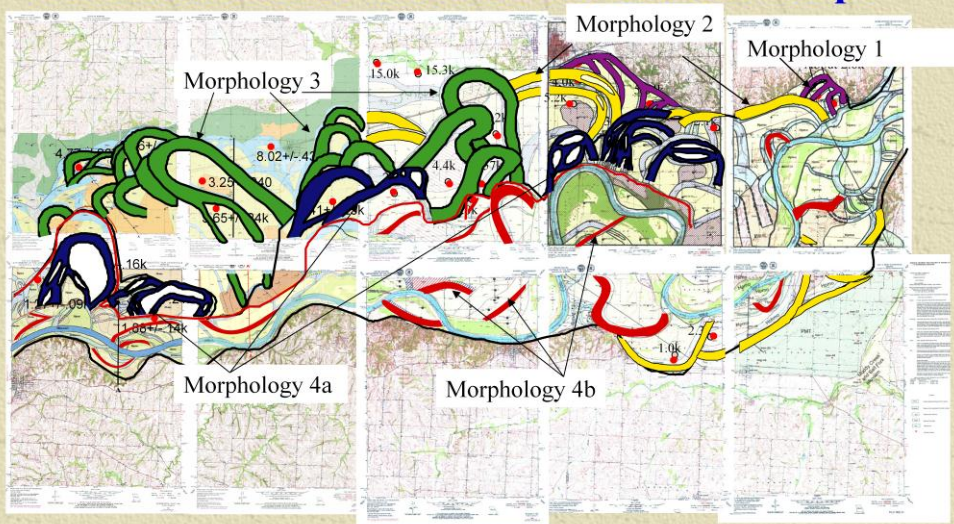
The Unstable Nature of Pattern

Morph-Styles Of the Holocene Alluvial Set



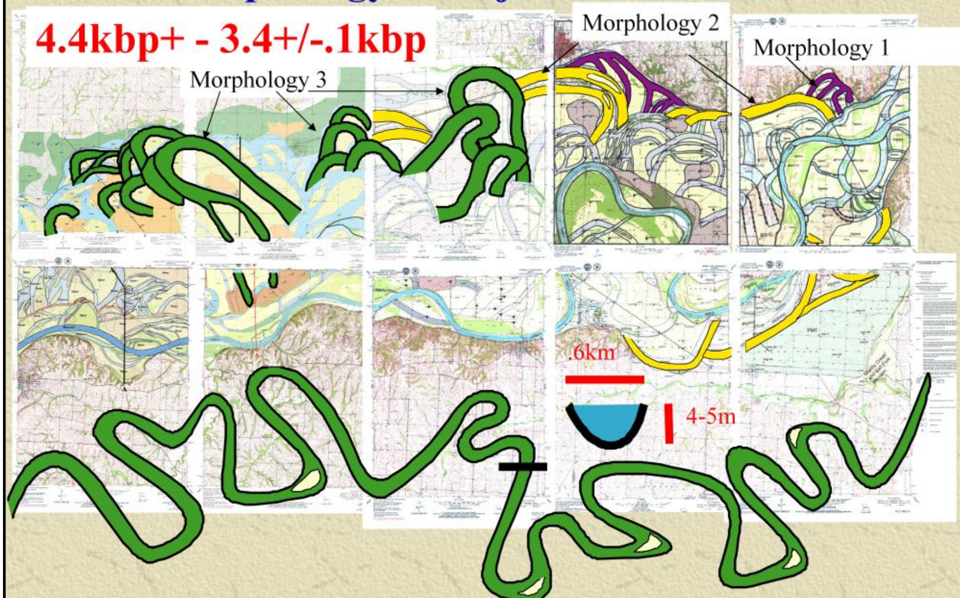
The Unstable Nature of Pattern

OSL Dates from Point-bars of Meander Loops

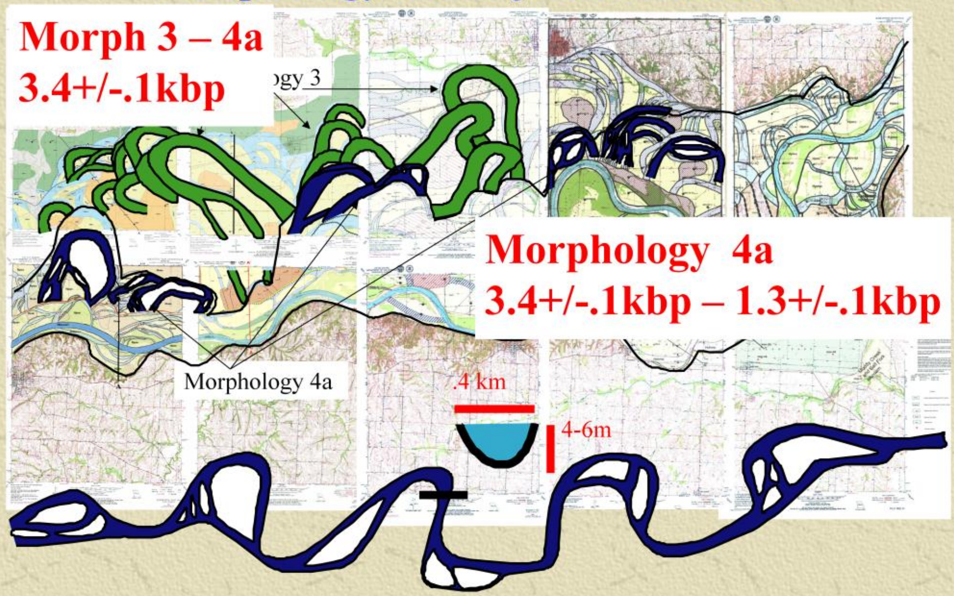


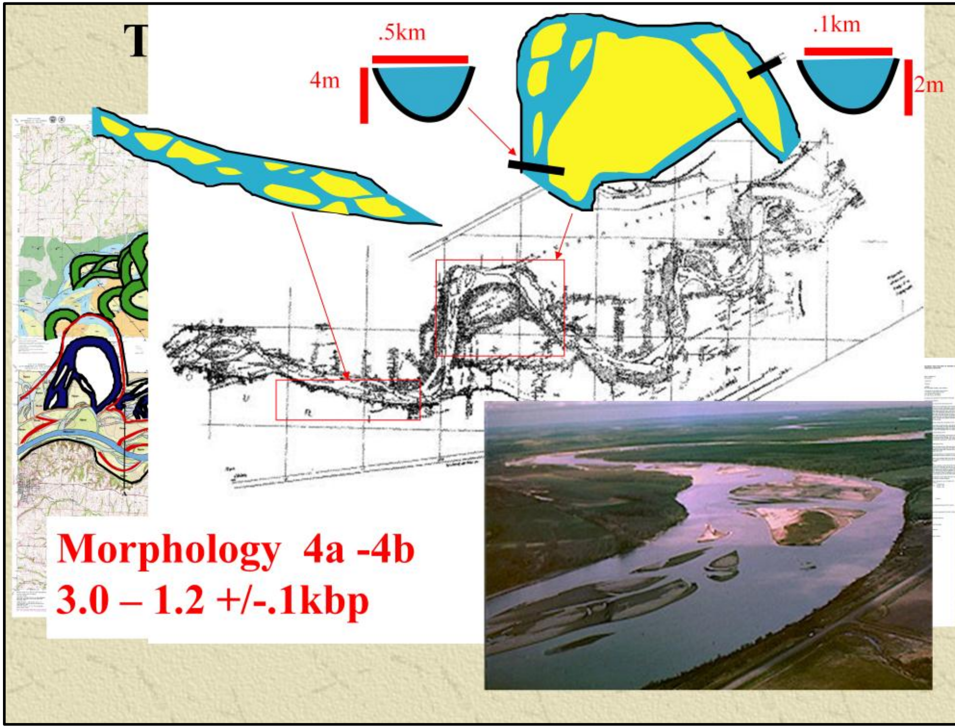
The Unstable Nature of Pattern

Morphology 3 Projected Channel



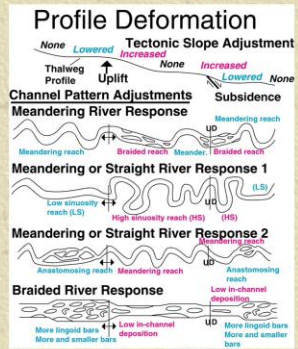
The Unstable Nature of Pattern
Morphology 4a Projected Channel




.5km
4m
.1km
2m
Morphology 4a -4b
3.0 – 1.2 +/-.1kbp

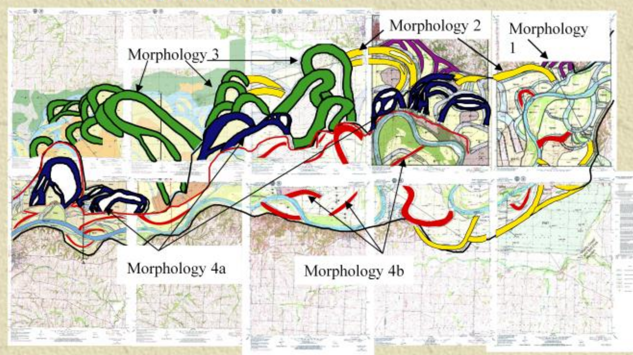
Controls on Channel Morphology

Tectonics



(Holbrook and Schumm, 1999)

All Since 4.5ka!



Climate

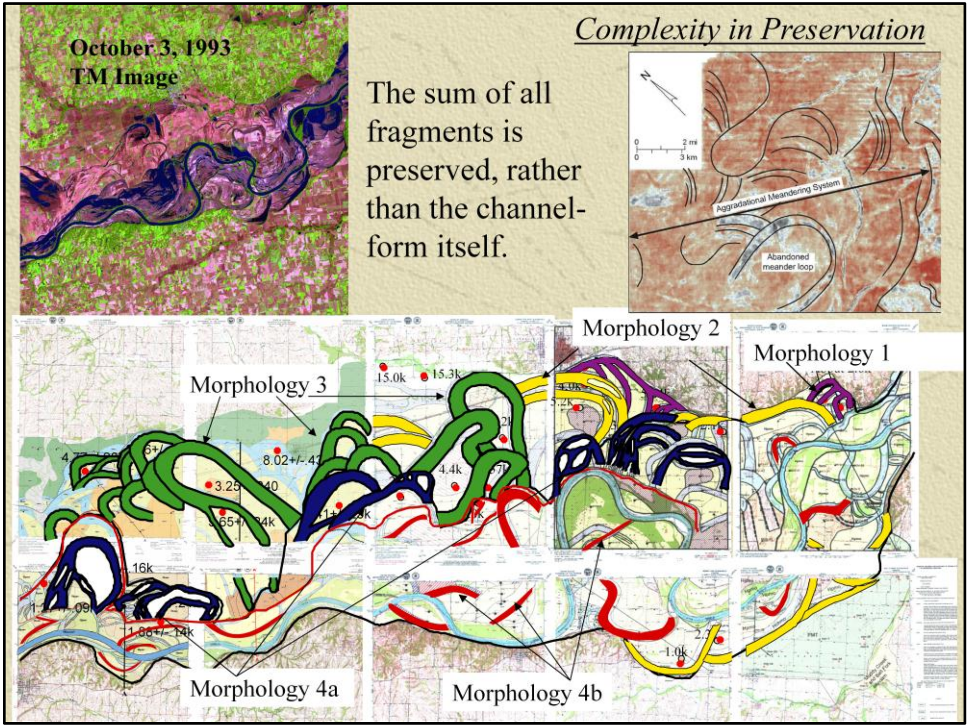
TABLE 4 Equations for Estimating Average Discharge $\overline{Q}$ for Various Categories of Bed and Bank Material

Category	Channel Sediment Characteristics[a] SC_{bd} (%)	SC_{bk} (%)	d_{50} (mm)	Equation Number	Expression for $\overline{Q}$	Number of Data Points	Standard Error (Log Units)
High silt-clay bed	61–100	—	<2.0	(57)	$0.031W_b^{2.12}$	15	0.15
Medium silt-clay bed	31–60	—	<2.0	(58)	$0.033W_b^{1.76}$	17	0.23
Low silt-clay bed	11–30	—	<2.0	(59)	$0.031W_b^{1.73}$	30	0.33
Sand bed, silt banks	1–10	70–100	<2.0	(60)	$0.027W_b^{1.69}$	33	0.23
Sand bed, sand banks	1–10	1–69	<2.0	(61)	$0.029W_b^{1.62}$	96	0.30
Gravel bed	—	—	2–64	(62)	$0.023W_b^{1.81}$	42	0.22
Cobble bed	—	—	>64	(63)	$0.024W_b^{1.84}$	19	0.11

SOURCE: Osterkamp and Hedman, 1982.

[a] SC_{bd} = silt-clay content of bed material; SC_{bk} = silt-clay content of bank material; d_{50} = diameter size of particles for which 50% of the distribution is finer; W_b = active-channel width.

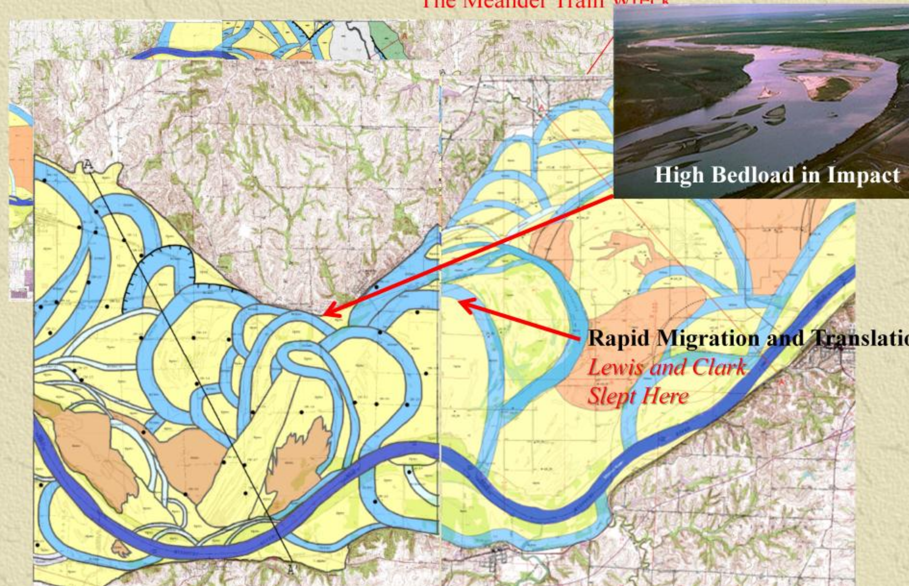
(Williams, 1985)



Presenter's notes: Floodplains are fragments of past rivers and not a bunch of complete rivers matching a single complete river pattern. In the seismic image at the top right, multiple fragments of a large meandering channel belt are visible including meander scrolls, abandoned meander loops and parts of the edge of the meandering channel belt. This image in particular illustrates the size that belts and floodplains can be, as we are often only able to see a fraction of the entire system in seismic compared to potential floodplain size.

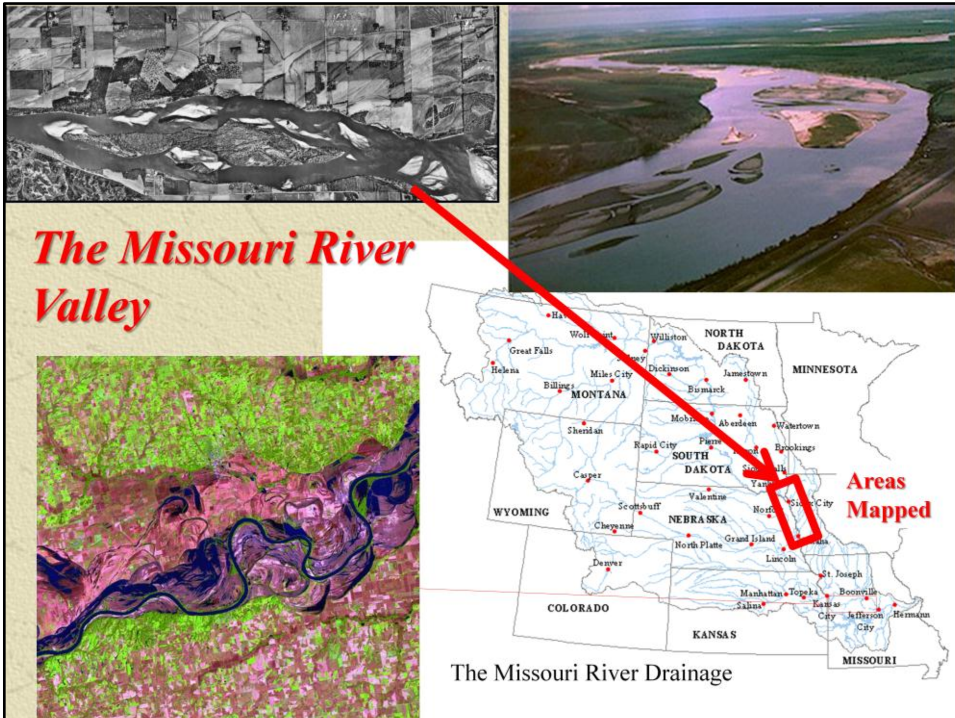
The Wreck

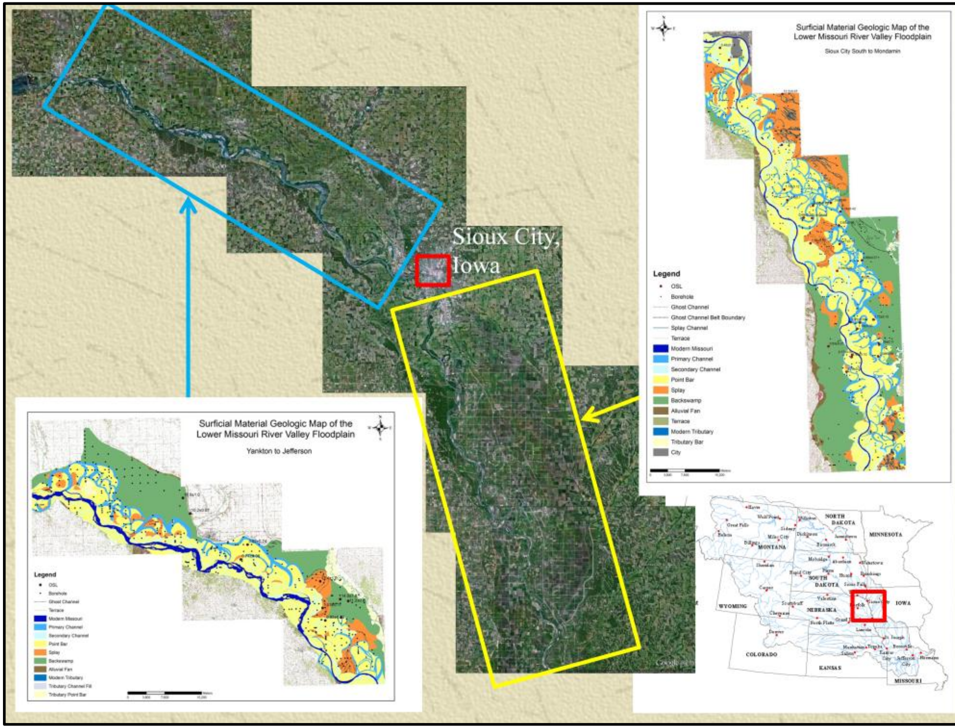
The Meander Train Wreck



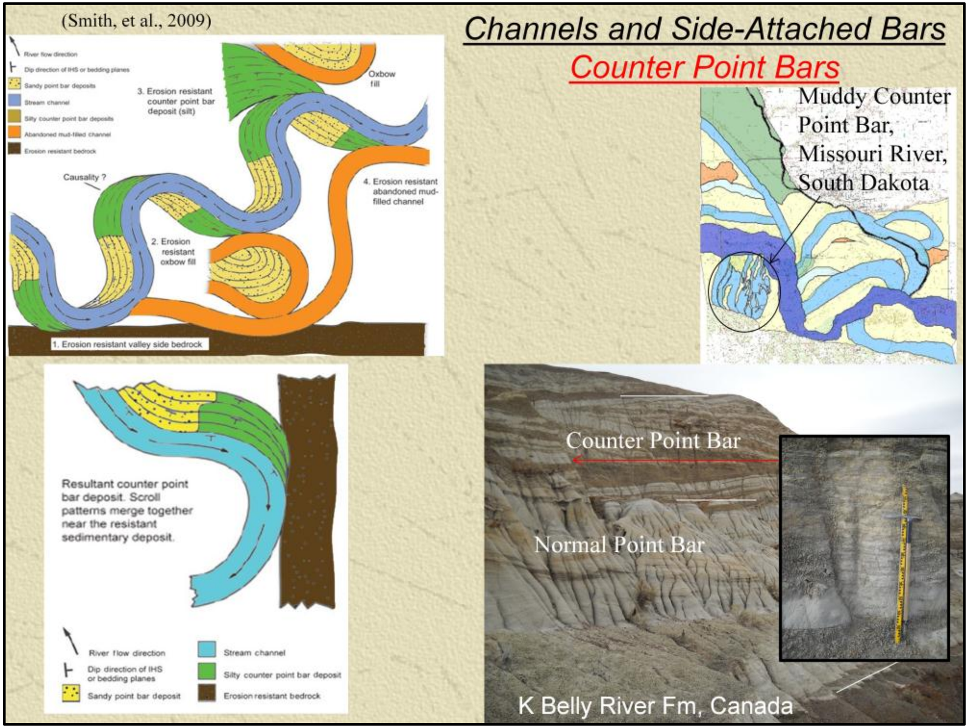
Rapid Migration and Translation

Lewis and Clark Slept Here


The Missouri River Valley
Areas Mapped
The Missouri River Drainage
NORTH DAKOTA
MINNESOTA
MONTANA
SOUTH DAKOTA
WYOMING
NEBRASKA
COLORADO
KANSAS
MISSOURI
Great Falls
Helena
Billings
Miles City
Williston
Dickinson
Jamestown
Bismarck
Aberdeen
Watertown
Brookings
Sheridan
Rapid City
Pierre
Casper
Valentine
Scottsbluff
Cheyenne
North Platte
Grand Island
Lincoln
Denver
St. Joseph
Manhattan
Topeka
Boonville
Salina
Kansas City
Jefferson City
Hermann

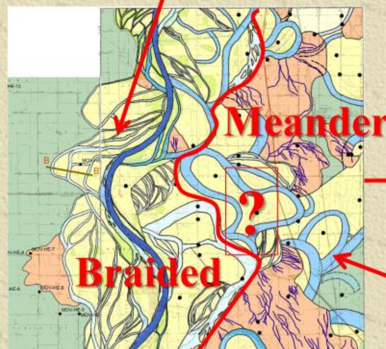


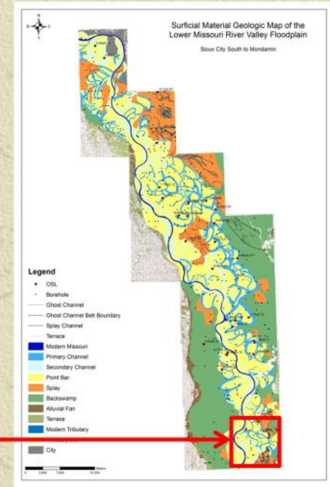
Sioux City, Iowa
Surficial Material Geologic Map of the Lower Missouri River Valley Floodplain
Sioux City South to Mondamin
Legend
OSL
Borehole
Ghost Channel
Ghost Channel Belt Boundary
Splay Channel
Terrace
Modern Missouri
Primary Channel
Secondary Channel
Point Bar
Splay
Backswamp
Alluvial Fan
Terrace
Modern Tributary
Tributary Bar
City
Surficial Material Geologic Map of the Lower Missouri River Valley Floodplain
Yankton to Jefferson
Legend
OSL
Borehole
Ghost Channel
Terrace
Modern Missouri
Primary Channel
Secondary Channel
Point Bar
Splay
Backswamp
Alluvial Fan
Modern Tributary
Tributary Channel Fill
Tributary Point Bar
NORTH DAKOTA
MINNESOTA
MONTANA
SOUTH DAKOTA
WYOMING
NEBRASKA
IOWA
COLORADO
KANSAS
MISSOURI



Presenter's notes: Counter point bars occur when bars migrate along the cutbank rather than the bar apex, either because of constriction of downstream bar translation. The slackwaters resulting tend to manifest as very fine-grained lateral accretion deposits.

The Spinout


Meander
?
Braided


Surficial Material Geologic Map of the
Lower Missouri River Valley Floodplain
Sioux City South to Mondamin
Legend
OSL
Borehole
Ghost Channel
Ghost Channel Belt Boundary
Splay Channel
Terrace
Modern Missouri
Primary Channel
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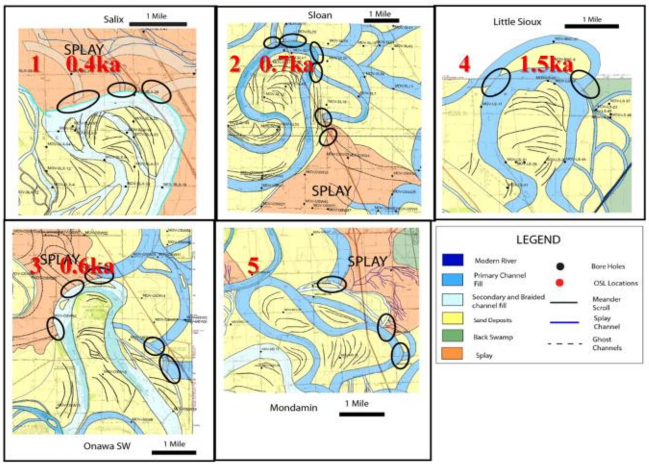
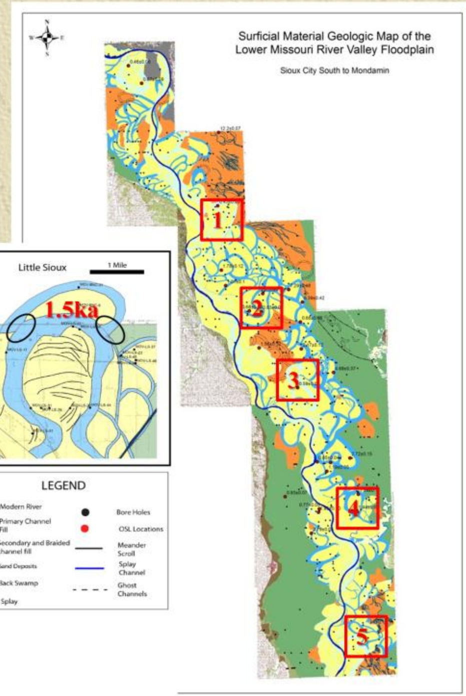
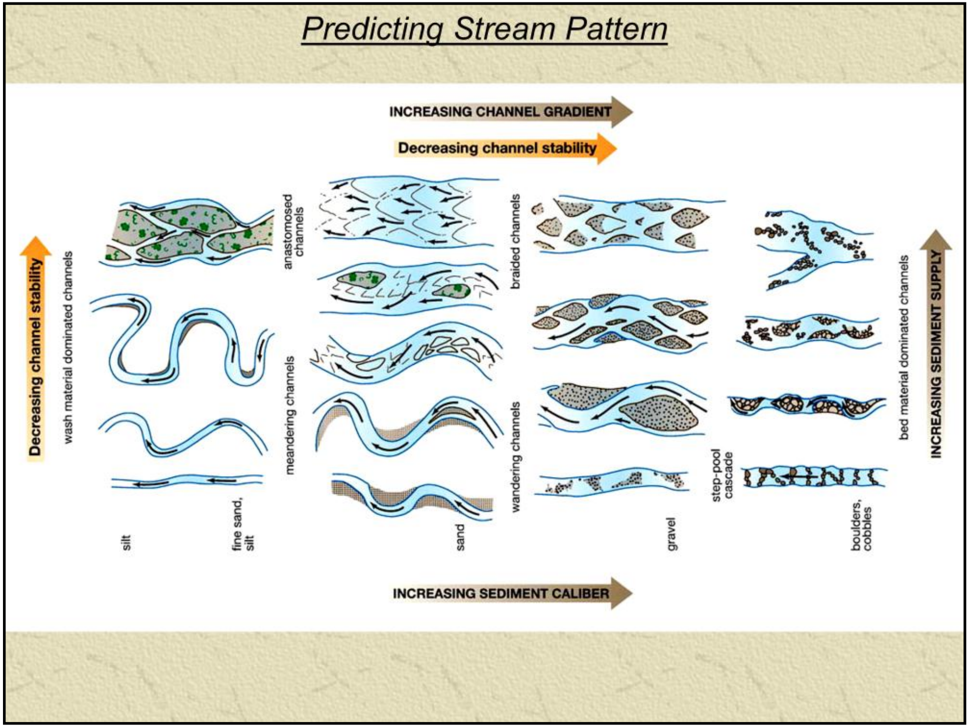
Alluvial Fan
Terrace
Modern Tributary
City

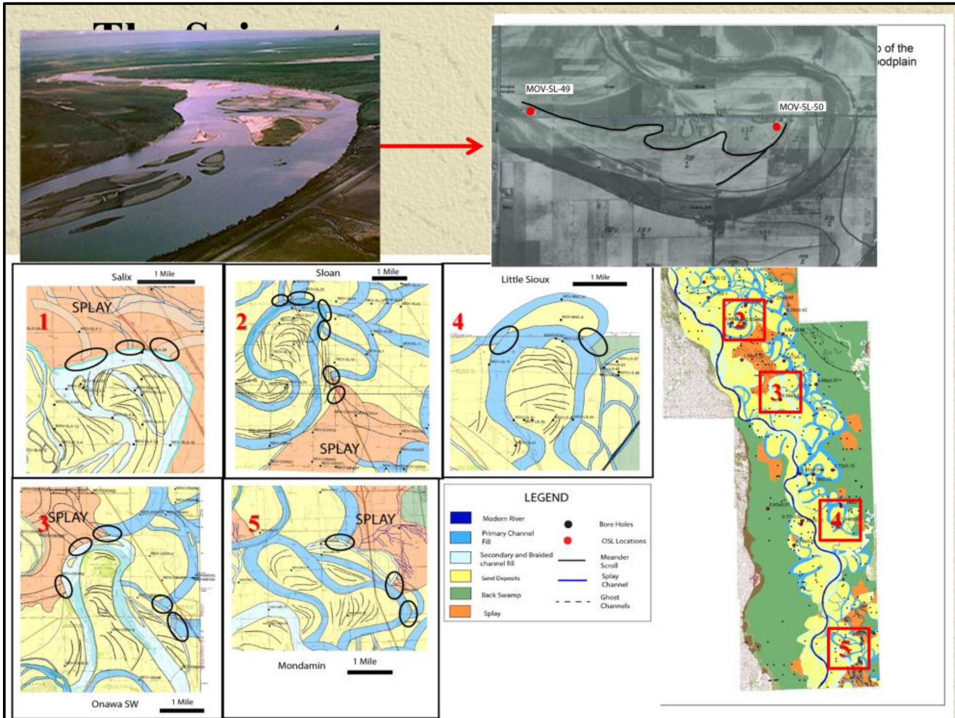
The Spinout


Salix
1 Mile
SPLAY
1 0.4ka
Sloan
1 Mile
2 0.7ka
SPLAY
Little Sioux
1 Mile
4 1.5ka
3 SPLAY 0.6ka
Onawa SW
1 Mile
5
SPLAY
Mondamin
1 Mile
LEGEND
Modern River
Primary Channel Fill
Secondary and Braided channel fill
Sand Deposits
Back Swamp
Splay
Bore Holes
OSL Locations
Meander Scroll
Splay Channel
Ghost Channels


Surficial Material Geologic Map of the
Lower Missouri River Valley Floodplain
Sioux City South to Mondamin
1
2
3
4
5



Presenter's notes: Predictability in river pattern is limited to generally observable trends in pattern shift of an existing river with shifts in controlling variables.

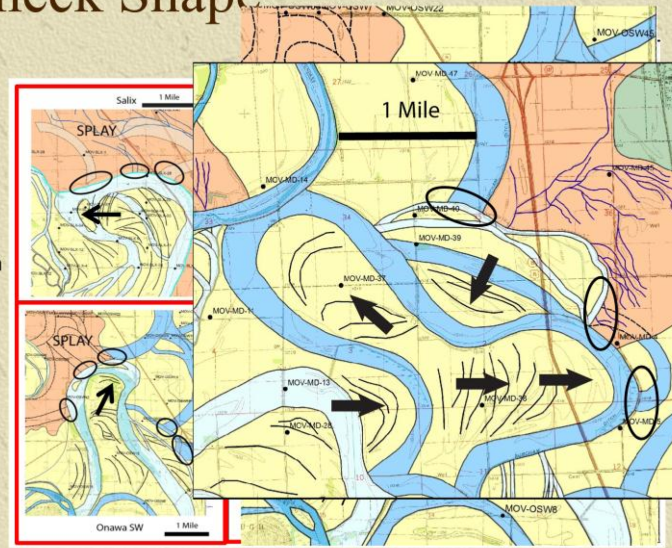

MOV-SL-49
MOV-SL-50
of the
odplain
Salix
1 Mile
SPLAY
1
Sloan
1 Mile
2
SPLAY
Little Sioux
1 Mile
4
SPLAY
3
Onawa SW
1 Mile
SPLAY
5
Mondamin
1 Mile
LEGEND
Modern River
Primary Channel Fill
Secondary and Braided channel fill
Sand Deposits
Back Swamp
Splay
Bore Holes
OSL Locations
Meander Scroll
Splay Channel
Ghost Channels
2
3
4
5

Gooseneck Shape

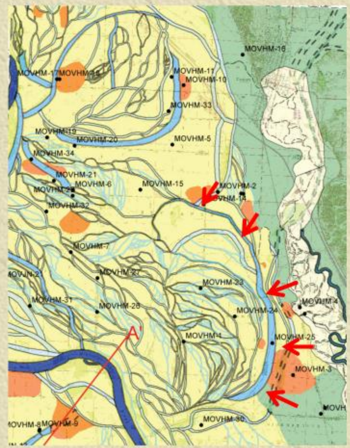
- There are 5 identifiable Gooseneck loops in the Study Area.
    - Salix
    - Sloan
    - Onawa SW
    - Little Sioux
    - Mondamin

- They all have one thing in common.
    - They cut into more easily erodible material
        - e.g. Sand

- Channel fill mud plugs and splay deposits act as deterrents. *(Hudson & Kessel, 2000)*



The Waver



MOVHM-16
MOVHM-17
MOVHM-11
MOVHM-10
MOVHM-33
MOVHM-19
MOVHM-20
MOVHM-5
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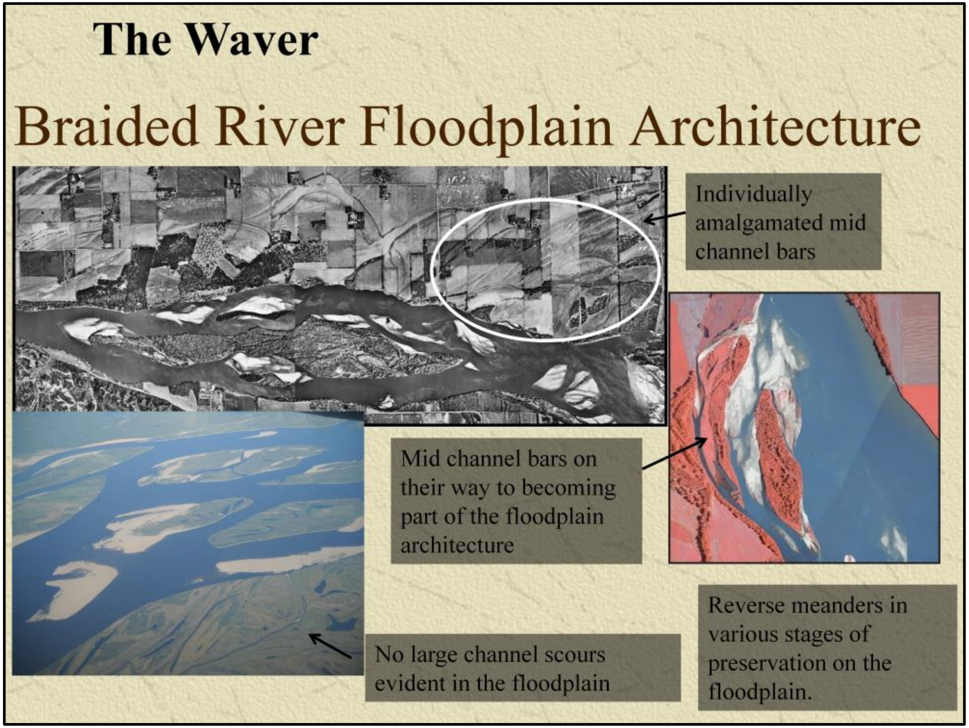
MOVHM-21
MOVHM-6
MOVHM-15
MOVHM-2
MOVHM-32
MOVHM-7
MOVHM-27
MOVHM-23
MOVHM-31
MOVHM-28
MOVHM-24
A'
MOVHM-25
MOVHM-3
MOVHM-30

Google earth



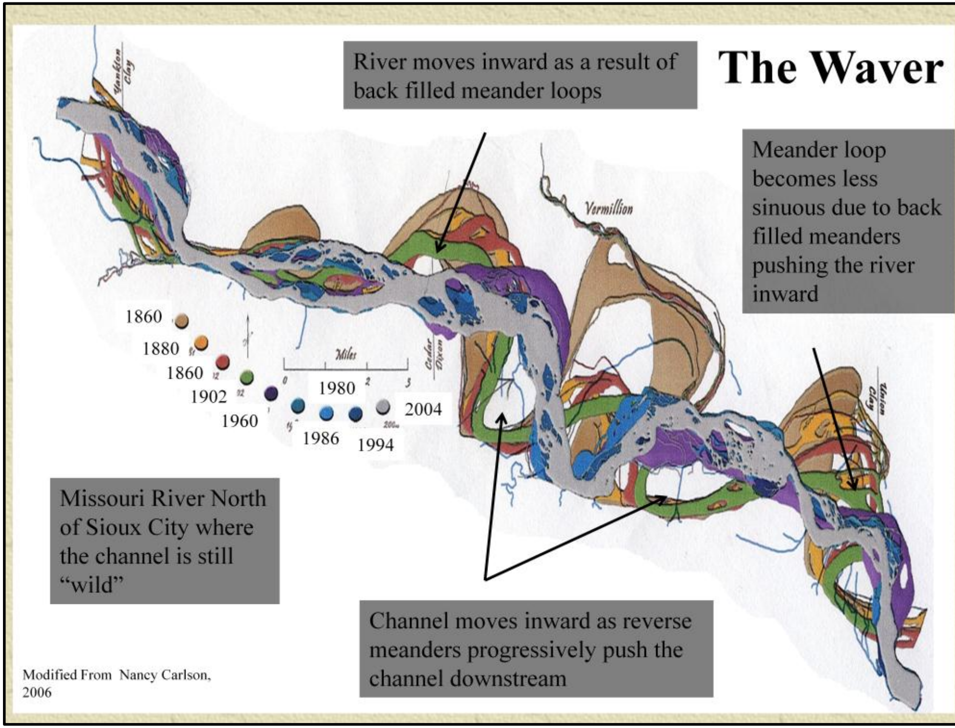
Presenter's notes: The real story here is that these mid channel bars are a second method to creating meanders in braided river. In addition, that they can move any direction they please.

Range of Bar Accretion Locations

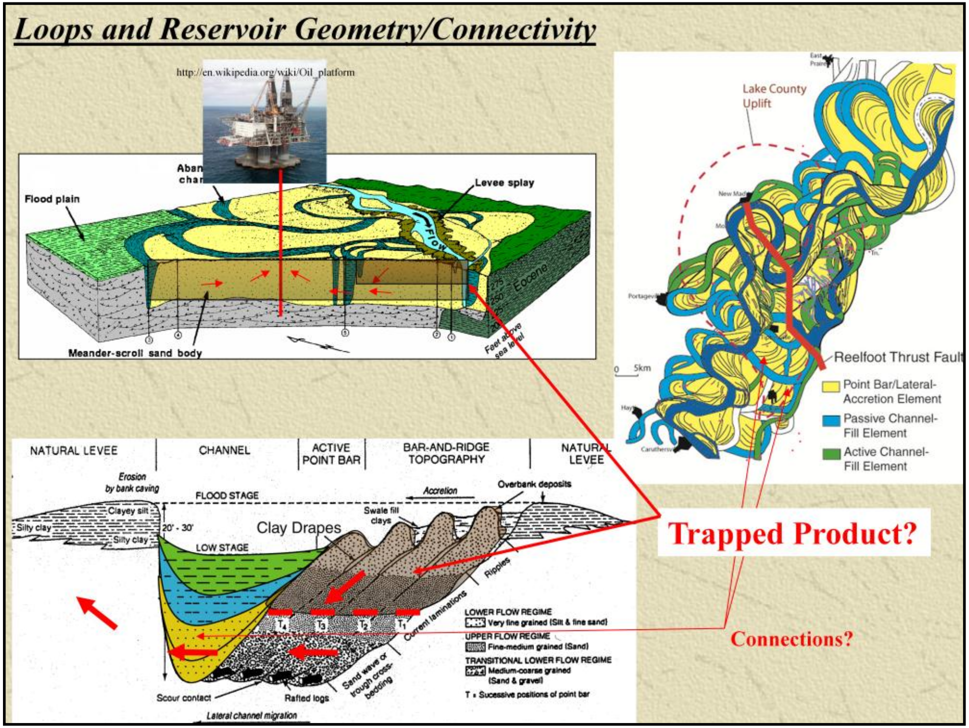
The Waver

Classic vs. Wavering bar

Red River Near Burneyville, Ok



Presenter's notes: Back filled meander loops can essentially move the channel in any direction. Note: they do not just affect one side of the channel bank.



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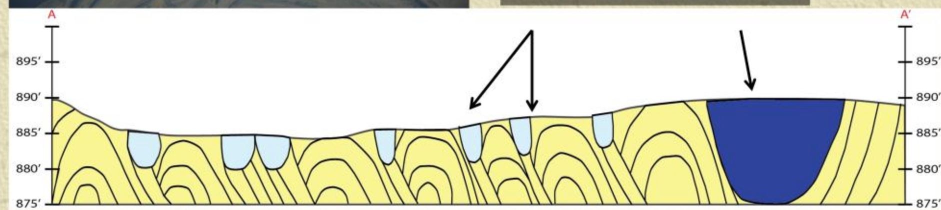
Hydrocarbon Reservoirs

Relative cross section of a reverse filled meander compared to the floodplain deposits that are left behind.

Notice only a large scour where the main channel cuts in. The secondary channels only leave small heterolithic deposits.



Presenter's notes: Back filled meanders on the other hand have a much more random accretionary process allowing for a more complex sand body. Overall, the deposit resembles more of a sand sheet with small heterolithic channels interrupting the sand deposits.

Conclusions

- Meanders are prone to abrupt chances in space and time.
- The usual suspects (i.e., point bars, counter, point bars) abound.
- Meanders also are pone to wrecks and spinouts.
- Braided rivers meander by bar accretion and tend to waver in all directions without true loop cutoff.
- All these patterns impact reservoir geometry.